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(54) An optical sensing system

(57) An optical sensing system comprises an optical fibre (4) arranged to be subjected along its length to fibre deforming forces during operation of the system and means (1) for producing coherent light signals for transmission along the optical fibre (4). The optical fibre (4) is provided along its length with a plurality of equally spaced discontinuities (5 to 11) which effectively divide the fibre (4) into a plurality of fibre elements so that a small proportion of each light signal being transmitted along the fibre (4) will be reflected back along the fibre from each of the discontinuities (5 to 11). In this way each reflected light signal after the first interferes with either the previously reflected signal from the preceding discontinuity or a reference light signal of the same frequency or a frequency with a constant difference frequency to the transmitted light signal to produce an electrical signal in photo-detection means 12. The difference between respective electrical signals corresponding to successive fibre elements is dependent upon the length of the fibre elements between discontinuities (5 to 11) so that changes in length of these elements produced by the incidence of deforming forces will result in changes in the electrical signals which will be detected.

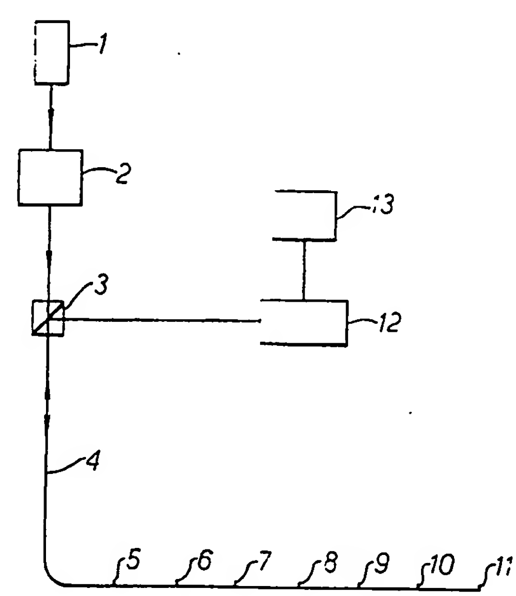

FIG. 1.

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SPECIFICATION

Improvements relating to optical sensing systems

This invention relates to optical systems for sensing strain or deformation (e.g. elongation or bending) of various members.

Although the present invention is especially concerned with hydrophones and the sensing of changes in length of an optical fibre in such hydrophones due to the impingement thereon of acoustic waves it should be understood that the invention is not limited to such application. In this connection many physical parameters can be converted by various well-known means such as moving coil meters, bi-metallic strips and Borden pressure gauges, into a displacement or deformation of some member which is dependent upon the particular parameter to be measured. Such parameters as temperature, pressure, electrical current or voltage could be measured in this way.

According to the present invention there is provided an optical sensing system comprising an optical fibre arranged to be subjected along its length to fibre deforming forces during operation of the system and means for producing coherent light signals for transmission along said optical fibre, in which the optical fibre is provided along its length with a number of equally spaced discontinuities which effectively divide the fibre into a plurality of discrete fibre elements so that a small proportion of each light signal being transmitted along the fibre will be reflected back along the fibre from each of the discontinuities whereby each reflected light signal after the first interferes with either the previously reflected signal from the preceding discontinuity or a reference light signal of the same frequency or a frequency with a constant difference frequency to the said transmitted light signal to produce an electrical signal in square law photo-detection means of the system, the difference between respective electrical signals corresponding to successive fibre elements being dependent upon the length of the fibre elements so that changes in length of these elements produced by the incidence of deforming forces will result in changes in the electrical signals which will be detected.

In carrying out the present invention a heterodyne system may be used in which two-pulse signals each comprising two pulses of slightly different frequencies $F+\Delta F$ and of pre-determined duration and time relationship are transmitted along the optical fibre, small proportions of the pulses being reflected back at each fibre discontinuity. The signal reflected from the second fibre discontinuity is caused to interfere with that reflected from the first discontinuity (i.e. the pulse of frequency F of the second reflected signal is heterodyned with the pulse of frequency $F+\Delta F$ of the first reflected signal). The heterodyning produces a detectable electrical beat frequency signal the modulation of which will vary with changes in length of the first optical fibre element between the first and second optical fibre discontinuities. It will be appreciated that signals reflected from the third, fourth and fifth and last discontinuities will similarly interfere with those signals reflected from the preceding discontinuity.

Thus, by detecting and measuring phase modulation of the electrical beat signals corresponding to the respective optical fibre elements between discontinuities any changes in length of such elements due to their being stressed can be determined.

The present invention also envisages as an alternative heterodyne system to that just described one in which a single pulse light signal of frequency F is transmitted down the optical fibre for reflection from the fibre discontinuities whilst a two-pulse signal comprising consecutive pulses of frequencies F and ΔF, respectively, is used as a continuous reference at the photodetection means to beat with the reflected signals of frequency F. In this case, however, it is necessary to make comparison between the difference frequencies arising from consecutive reflections and this will require some means of electronically delaying or storing the information from the preceding reflection in order to compare electrical phase relationships.

As an alternative system to the systems just described, reflected signals from the optical fibre discontinuities may be homodyned by arranging that one or two pulses in predetermined time relationship and of the same frequency are transmitted along the optical fibre and reflected signals from the respective discontinuities except the first are caused to interfere with the signals reflected from the preceding discontinuities to produce amplitude modulated electrical signals in dependence upon the lengths of the optical fibre elements. The detection means will detect and/or measure any changes in modulation due to deformation of the fibre elements.

As will be fully appreciated from the foregoing the sensing system according to the present invention is especially applicable to optical beamforming acoustic wave sensors in which the elements of the optical fibre define an acoustic wave sensor array for use in hydrophones for sonar purposes.

As previously mentioned the present invention has many different applications but because of the non-conductive nature of the optical fibre sensing arrangement it would be of particular advantage in explosive gas or vapour environments, such as coal mines, petrol and chemical plants etc.

By way of example the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 shows a schematic diagram of one optical fibre deformation detection system according to the invention; and,

Figures 2 and 3 show pulse diagrams relating

to alternative systems for measuring optical fibre deformation.

Referring to Figure 1 of the drawing a pulsed laser 1 produces an output pulse of coherent light of frequency 1 which is fed into an optical switch means 2 wherein a modulated pulse of frequency $F+\Delta F$ is produced which by the inclusion of delay means in the optical switch means lags behind the pulse of frequency F by a predetermined time interval T. This two-pulse light signals passes through a beam splitter 3 and is focussed into an optical fibre 4.

Equispaced discontinuities 5 to 11 are provided along the optical fibre and these discontinuities may, for example, be formed by suitable joints in the optical fibre. The fibre is effectively divided by these discontinuities into six sensing elements and variations in the lengths of these fibre elements, such as due to the impingement thereon of acoustic waves, can be detected and measured in the manner now to be described.

As each two-pulse light signal reaches the first optical fibre discontinuity 5 a small proportion of the signal will be reflected back along the fibre 4 to the beam splitter 3 which directs the signal to a photodetector 12. The remaining part of the two-pulse signal travels on to discontinuity 6 at which a further small proportion thereof will be reflected back along the optical fibre 4 to the detector 12. This procedure continues until that part of the two-pulse signal remaining reaches the last of the optical fibre discontinuities 11 and a small proportion of this signal is again reflected back along the optical fibre to the detector 12. A further two-pulse optical transmission is then made and the cycle repeated.

Referring now to Figure 2 of the drawing this shows by way of example reflections of the two-pulse signals from the discontinuities 5, 6 and 7. As can be seen from the drawing the reflection from the second discontinuity 6 in the present example is delayed with respect to the reflection from the first discontinuity 5 by time T.

$$T=\frac{2L}{C_G}$$

where

L=the length of each optical fibre element and C_G=velocity of light in the optical fibre.

By the appropriate choice of length L the delay between the reflections is such that there is total coincidence or at least some overlap between the reflected pulse of frequency F of a later reflected signal with the pulse of frequency $F+\Delta F$ of the preceding reflected signal. The reflected pulses are heterodyned in the square law photodetector 12 to produce beat or modulated signals as shown and the phase modulation of these signals will vary in dependence upon variations in length of the optical fibre elements. Accordingly, by detecting and measuring the phase modulation of the beat signals by means of a phase detector 13 changes in length of the optical fibre elements and thus deformation forces acting on these elements can be measured.

Referring now to Figure 3 of the drawings this shows the pulse diagram of an alternative sensing system in which the pulsed laser will produce at predetermined intervals one or two closely spaced pulses of the same frequency which constitute the signals fed to the optical fibre 4 (Figure 1) without the intervention of the optical switch means 2 (Figure 1). Assuming single-pulse signals are transmitted to the optical fibre the signals reflected from the discontinuities 5, 6 and 7 will be as shown in Figure 3. The reflected signals are homodyned and the changes in amplitude of the electrical signals produced by changes in length of the optical fibre elements will be detected by the phase photodetector 12 (Figure 1). The phase detector 13 is not required for this embodiment.

When the embodiments just above described are used in a hydrophone the free end of the optical fibre including the discontinuities 5 to 11 will be trailed through the water and will provide a beamforming acoustic wave sensor array which will respond to acoustic waves impinging on the optical fibre sensing elements to produce variations in the lengths thereof which will be measured in the manner described.

As will be appreciated from the foregoing the present invention enables a single optical fibre sensor to be used as a beamforming array instead of using a plurality of separate sensors which can be inconvenient and expensive. The simple and relatively cheap provision of a beamforming acoustic sensor array provided by the invention also has the advantage of requiring access to one end only of the optical fibre which facilitates trailing of the fibre behind a vessel and which is compatible with the desensitisation of that part of the optical fibre between the signal generating and phase detection means and the fibre sensing elements.

Claims (Filed on 15.6.83)

1. An optical sensing system comprising an optical fibre arranged to be subjected along its length to fibre deforming forces during operation of the system and means for producing coherent light signals for transmission along said optical fibre, in which the optical fibre is provided along its length with a plurality of equally spaced discontinuities which effectively divide the fibre into a plurality of discrete fibre elements so that a small proportion of each light signal being transmitted along the fibre will be reflected back along the fibre from each of the discontinuities whereby each reflected light signal after the first interferes with either the previously reflected signal from the preceding discontinuity or a reference light signal of the same frequency or a frequency with a constant difference frequency to the same transmitted light signal to produce an electrical signal in photo-detection means, the difference between respective electrical signals corresponding to successive fibre elements being

dependent upon the length of the fibre elements so that changes in length of these elements produced by the incidence of deforming forces will result in changes in the electrical signals which will be detected.

2. An optical sensing system as claimed in claim 1, in which two-pulse signals each comprising pulses of slightly different frequencies (F and F+F) and of predetermined duration and time relationship are transmitted along the optical fibre so that small proportions of the pulses are reflected back at each fibre discontinuity, in which the signal reflected from the second fibre discontinuity is caused to interfere or is heterodyned with that reflected from the first discontinuity to produce a detectable electrical beat frequency signal the modulation of which will vary with changes in length of the first optical fibre element between the first and second optical fibre discontinuities and signals reflected from the third, fourth, fifth and last discontinuities, as the case may be, will similarly interfere with those signals reflected from the preceding discontinuity.

3. An optical sensing system as claimed in claim 1, in which a single pulse light signal of frequency (F) is transmitted down the optical fibre for reflection from the fibre discontinuities whilst a two-pulse signal comprising consecutive pulses of slightly different frequencies (F and F+F) is utilised as a continuous reference at the photo-detection means to beat with the reflected signals of frequency (F), and in which means are provided to electronically delay or store information from a preceding reflection in order to make a comparison between the phase relationships of consecutive reflections.

4. An optical sensing system as claimed in claim 1, in which signals reflected from the optical fibre discontinuities are homodyned by arranging that one or two light pulses in predetermined time relationship and of the same frequency, are transmitted along the optical fibre and reflected signals from the respective discontinuities except the first are caused to interfere with the signals reflected from the preceding discontinuities to produce amplitude-modulated electrical signals in dependance upon the lengths of the optical fibre elements, the photo-detection means detecting and/or measuring any changes in modulation due to deformation of the fibre elements.

5. An optical sensing system substantially as hereinbefore described with reference to the accompanying drawings.

6. Hydrophone equipment embodying an optical sensing system as claimed in any preceding claim.

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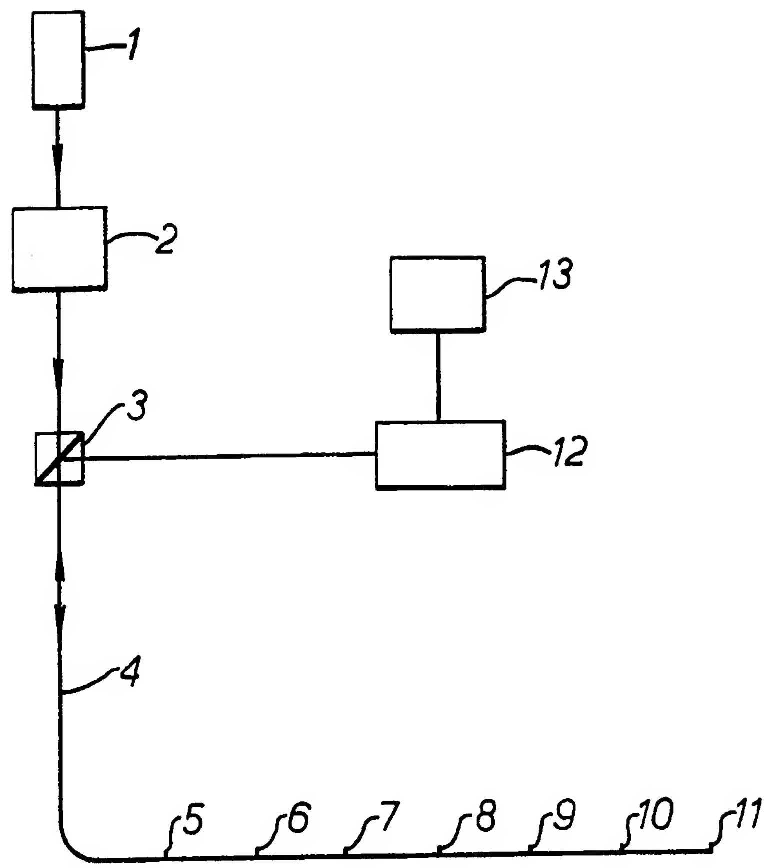
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FIG. 1.

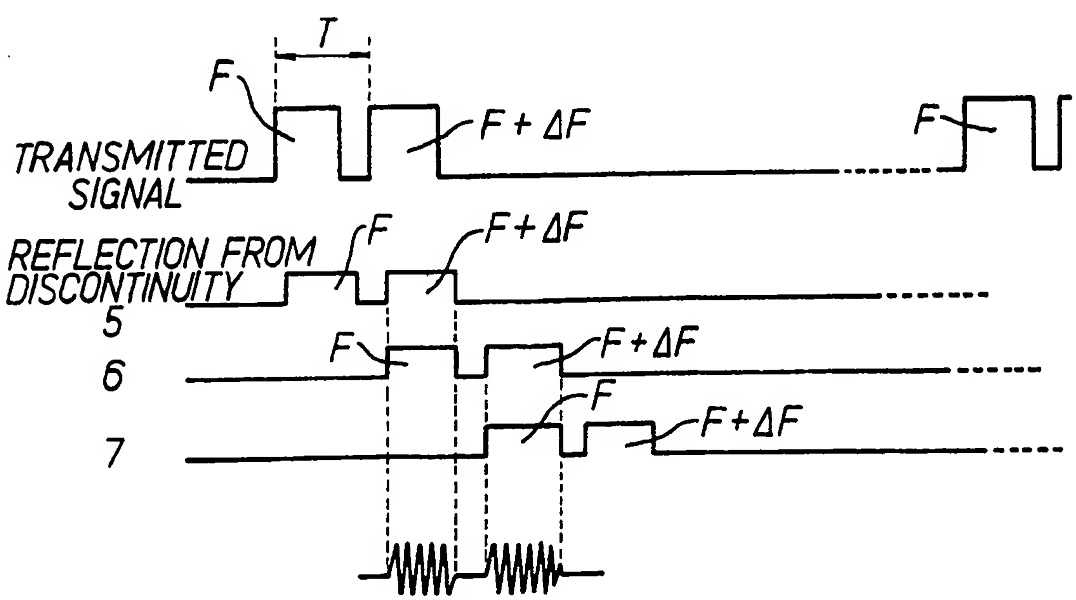
T
F
F + ΔF
TRANSMITTED SIGNAL
F
REFLECTION FROM DISCONTINUITY 5
F
F + ΔF
F
F + ΔF
6
F
F + ΔF
7

FIG. 2.

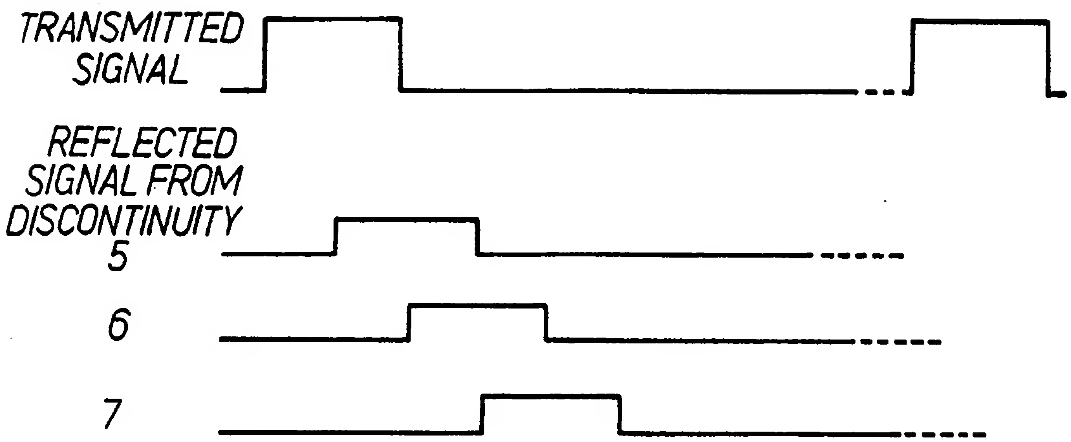
TRANSMITTED SIGNAL
REFLECTED SIGNAL FROM DISCONTINUITY
5
6
7

FIG. 3.